COMMAND, CONTROL, COMMUNICATIONS AND AUTOMATION NEEDS FOR THE COMBINED ARMS TEAM

A thesis presented to the faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements for the degree

MASTER OF MILITARY ART AND SCIENCE

by

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B.S., Alcorn State University, Lorman, Mississippi, 1980

Fort Leavenworth, Kansas
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The Command, Control, Communications and Automation Needs for the Combined Arms Team

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Command and control becomes increasingly important in synchronization, operational tempo, and increased situational awareness on the modern battlefield. These capabilities ensure commanders will be able to operate within the decision cycles of any potential adversary. The Army is wrestling with the problems of independent development of major weapons systems and the inability of those systems to communicate with each other. Command and control of these systems are of paramount importance to fighting forces because more frequently commanders will make decisions based on automated information databases. This study has shown that the influences of rapidly advancing technology and increasing need for information on the modern battlefield will place untenable demands on any automated command and controls system. This analysis has shown that current technology offers limited opportunities for eliminating information overload and that tactical command and control systems will become bogged down during periods of peak loading.

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The opinions and conclusions expressed herein are those of the student author and do not necessarily represent the views of the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

ABSTRACT

THE COMMAND, CONTROL, COMMUNICATIONS AND AUTOMATION NEEDS FOR THE COMBINED ARMS TEAM by MAJ Peter R. Barnes, USA, 89 pages.

This study assesses the adequacy of the Army Command and Control Systems with respect to the significant increases in mobility, lethality, and capabilities of advanced weapons systems. Command and control becomes increasingly important in synchronization, operational tempo, and increased situational awareness on the modern battlefield. These capabilities ensure commanders will be able to operate within the decision cycles of any potential adversary.

The Army is wrestling with the problems of independent development of major weapons systems and the inability of those systems to communicate with each other. Command and control of these systems are of paramount importance to fighting forces because more frequently commanders will make decisions based on automated information databases.

This study has shown that the influences of rapidly advancing technology and increasing need for information on the modern battlefield will place untenable demands on any automated command and control system. This analysis has shown tht current technology offers limited opportunities for eliminating information overload, therefore a tactical command and control system can become bogged down during periods of peak loading.

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LIST OF ILLUSTRATIONS

LIST OF ABBREVIATIONS

AB2	ARMY BRIGADE AND BELOW
ABCS	ARMY BATTLE COMMAND SYSTEM
AC2MP	ARMY COMMAND AND CONTROL MASTER PLAN
ACU	ARMY COMMON USER
ADDS	ARMY DATA DISTRIBUTION SYSTEM
AFATDS	ADVANCED FIELD ARTILLERY TACTICAL DATA SYSTEM
ALOC	ADMINISTRATIVE AND LOGISTICS OPERATIONS CENTER
ANBCIS	ADVANCED NUCLEAR, BIOLOGICAL AND CHEMICAL INFORMATION ASAS ALL-SOURCE ANALYSIS SYSTEM
ATCCS	ARMY TACTICAL COMMAND AND CONTROL SYSTEM
AWIS	ARMY WORLD-WIDE COMMAND AND CONTROL INFORMATION SYSTEM
BCBL	BATTLE COMMAND BATTLE LABORATORY
BCV	BATTLE COMMAND VEHICLE
BECS	BATTLEFIELD ELECTRONIC CEOI SYSTEM
BFA	BATTLEFIELD FUNCTIONAL AREA
BOS	BATTLEFIELD OPERATING SYSTEM
C2	COMMAND AND CONTROL
C2V	COMMAND AND CONTROL VEHICLE
CAC	COMBINED ARMS COMMAND
CD-ROM	COMPACT DISK READ-ONLY MEMORY
CEOI	COMMUNICATIONS-ELECTRONICS OPERATING INSTRUCTIONS
CHS	COMMON HARDWARE/SOFTWARE
CNR	COMBAT NET RADIO
COEA	COST AND OPERATIONAL EFFECTIVENESS ANALYSIS
COMINT	COMMUNICATIONS INTELLIGENCE
CP	COMMAND POST
CSS	COMBAT SERVICE SUPPORT
CSSCS	COMBAT SERVICE SUPPORT CONTROL SYSTEM
DOD	DEPARTMENT OF DEFENSE
DSA	DEEP AND SIMULTANEOUS ATTACK
EELS	EARLY ENTRY, LETHALITY, AND SURVIVABILITY
ELINT	ELECTRONIC INTELLIGENCE

FAADC2	FORWARD AREA AIR DEFENSE COMMAND AND CONTROL SYSTEM
GCS	GUARDRAIL COMMON SENSOR
IER	INDEPENDENT EVALUATION REPORT
IEW	INTELLIGENCE AND ELECTRONIC WARFARE
IHFR	IMPROVED HIGH FREQUENCY RADIO
IPB	INTELLIGENCE PREPARATION OF THE BATTLEFIELD
JSTARS	JOINT SURVEILLANCE AND ATTACK RADAR SYSTEM
LBA	LONGBOW APACHE
LCU	LIGHTWEIGHT COMPUTER UNIT
MB	MEGABYTE
MCS	MANEUVER CONTROL SYSTEM
MFA	MANEUVER FUNCTIONAL AREA
MHz	MEGAH TZ
MSE	MOBILE SUBSCRIBER EQUIPMENT
MSEU	MASS STORAGE EXPANSION UNIT
NAM	NETWORK ASSESSMENT MODEL
NRC	NATIONAL RESEARCH COUNCIL
OSI	OPEN SYSTEMS INTERFACE
PC	PERSONAL COMPUTER
PPBES	PLANNING, PROGRAMMING, BUDGETING AND EXECUTION SYSTEM
RAM	RANDOM ACCESS MEMORY
SINCGARS	SINGLE CHANNEL GROUND AND AIRBORNE RADIO SYSTEM
SOI	SIGNAL OPERATING INSTRUCTIONS
STACCS	STANDARD THEATER ARMY COMMAND AND CONTROL SYSTEM
STAR	STRATEGIC TECHNOLOGIES FOR THE ARMY OF THE 21ST CENTURY
TACSAT	TACTICAL SATELLITE
TADS/PNVS	TARGET ACQUISITION DESIGNATION SIGHT AND PILOT NIGHT VISION SENSOR
TCU	TRANSPORTABLE COMPUTER UNIT
TOC	TACTICAL OPERATIONS CENTER
TRADOC	TRAINING AND DOCTRINE COMMAND

CHAPTER 1

INTRODUCTION

The Army Materiel Command is responsible for the development, production, and acquisition of major and non-major systems for use by Army forces. The Army Command and Control Master Plan (AC2MP) delineates future modernization efforts for communications systems for tactical forces. The AC2MP guides the acquisition of automation and communications devices for Army echelons from corps down to battalion. Each major branch, center, and school is responsible for developing weapon systems peculiar to its mission along with the associated command and control subsystems.

The Army realized that more effort is necessary to insure the compatibility of the multimillion dollar weapon systems that are either being developed or undergoing significant improvements. Experience in the acquisition environment indicates that incompatibility is fostered by parochialism inherent in military procurement and "stovepipe" architectural development. Such voids of cooperation within the Army and between branches of the services are not uncommon. A Joint Requirements Oversight Council was developed to better manage major acquisitions by services and to eliminate redundant systems developments. The umbrella approach for managing major system acquisition, the Defense Acquisition Process mandated by Department of Defense (DOD) Directive 5000.1, required that major systems go through screening for applicability to other services prior to program approval. Billions of dollars are being spent to improve the efficiency and effectiveness of the combined arms team.[1] Command and Control (C2) must keep pace with the enhancements of the force at large.

Automation technology today has a significantly shorter life span than just a few years ago. This contention lies in conflict with the 12-17 year development cycle for Army acquisition. Processors, information media, display systems and practically every other component of information technology are advancing at astronomical rates. Designers of military command and control systems will be challenged to remain abreast of these changes to optimize capability, technology, and cost. The Army is moving toward a digitized battlefield that takes advantage of the explosion in communication and automation capabilities and the unprecedented availability of information. The next war may be inundated with multiple integrated command, control, and information systems that extend from the National Command Authority to platoon leaders in foxholes. This thesis examined the Army command and control structure at the tactical level and its ability to effectively integrate members of the combined arms team.

Command and Control Defined

The Department of Defense in the Joint Chiefs of Staff Publication 1 defines command and control as follows:

> [Command and control is] the exercise of authority and direction by a purposely designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning, directing, coordinating, and controlling forces and operations in the accomplishment of the mission.[2]

This broad definition is a prelude to the multitude of interpretations and opinions on this elusive subject, Command and Control. For purposes of illustration, it may be clearer to separate these two terms.

The Force Projection Army Command and Control (FORCEPAC2) Action Plan, the most current Army position on C2, defines "command" as "the art of providing focus, guidance and motivation to soldiers . . . the tools of human nature . . . [including] a human bond, a moral or physical presence that soldiers feel . . . ."[3] The command process includes several personal functions driven by the commander's personality, education, intuition and environment to which he was exposed. They extend from his cognitive, anticipatory, and decision-making abilities during times of stress. This thesis avoided the abstract dimension of the C2 process but acknowledged its existence and influence on the battlefield.

On the other hand, "control" is more precise and scientific. "It provides more structure and it must keep pace with technology."[4] Today the science of control is more influenced by electronic communications, processing, and display systems than ever before.

> Control of the force is accomplished through the management of personnel, equipment, facilities, and procedures in planning, coordinating, and controlling forces and operations in the accomplishment of the mission.[5]

For the purpose of clarity, the command and control process is defined as the combination of the technical aspects of control described earlier and the tangible elements of command. To the contemporary student of command and control, this concept is "battle command."

> [Battle command is] the ability to envision the activities over time and space to achieve an endstate, translate and communicate that vision into a brief but clear intent, formulate concepts, and provide the force of will through the presence of leadership throughout the battlefield that will cause the concentration of overwhelming combat power at the right time and place to win decisively with minimal friendly casualties.[6]

Battle command is much more complex than this definition. It is a new concept to the C2 community, and it "incorporates the ability to decide and the ability to lead."[7] There is a correlation between Battle Command and the Army's C2 model developed during the days of AirLand Battle Doctrine. This model described seven of the C2 tasks:

1. See the situation,
2. Evaluate the situation,
3. Develop the plans,
4. Allocate resources,
5. Coordinate the resources,

6. Fight the battles, and

7. Sustain the force.[8]

It is easier to visualize the influences of technology on the elements in this list than in the abstract descriptions previously mentioned. These concepts and terminology are in constant evolution. It is of little surprise that command and control are such ill-defined and little-understood concepts.

Perhaps rather than define command and control, a model for evaluating a command and control system is more appropriate. An effective command and control system is defined by the Defense Science Board Task Force on Command and Control Systems Management as follows:

> [Those] support systems that aid the commander in the exercise of command . . . [it is more than] a computer with its associated software and displays; it is not just communications links; and it is not just all the information processing and fusion that must go in any well-designed and well-operating command and control system. It is all of the above and more. The ideal command and control system supporting a commander is such that the commander knows what goes on, that he receives what is intended for him, and that what he transmits is delivered to the intended addressee, so that the command decisions are made with confidence and are based on information that is complete, true, and up-to-date.[9]

This definition suggests that a C2 system can be evaluated by what information is available to the commander at critical decision points during the battle.

This thesis focused on the scientific, measurable aspect of command and control: that part most influenced by technology. On a modern battlefield, decisive control cannot be accomplished adequately without a superior technological advantage. Successful commanders on the modern battlefield must acquire, process, and distribute information more quickly than their enemies to continue to operate within the enemy's decision cycle. He must not "attempt . . . to know everything. However, he must know that which is important."[10] Getting critical information to the commander is the true challenge for trained staffs with access to modern technology.

Command and Control Trends

As the Army builds the command posts (CPs) and tactical operations centers (TOCs) of the future, it must assess its requirements in communications, automation, and information management. The TOC of the future will have access to information from a multitude of sources. A commander could very easily become overwhelmed with useless and redundant data electronically intertwined with critically important information.

Today's tactical commander acquires most information about the battlefield from an intelligence preparation of the battlefield (IPB) prior to hostilities. An inadequate IPB and failures of intelligence collection, analysis and dissemination at the tactical level are well documented in Operation DESERT STORM after-action reports. Although this country possesses the most sophisticated collection systems in the world, useful intelligence rarely got to the tactical user. "The other half of the intelligence problem was dissemination, with imagery the biggest challenge. The intelligence system before DESERT STORM was not designed to push all the required intelligence down to the tactical level."[11] The Army Aviation Center's Desert Storm After-Action Report notes that numerous attack helicopter missions were futile because the pilots found the target area quite different from what was expected; the situation had changed during travel from assembly areas to engagement areas. The Allies' difficulties in tracking and killing SCUD missiles is also well publicized. "By January

24 CENTCOM had diverted 40 percent of all air sorties to SCUD hunting at a considerable cost to ARCENT's efforts to prepare the battlefield."[12]

Currently, the commander receives friendly pre-battle information from the operations order, and most of what he knows about actual fighting and the post battle comes from face-to-face meetings and voice radio. General Frederick Franks, Commander, VII Corps during Operation DESERT STORM, is well known for meeting with subordinate commanders and drawing the details for the pending operation in the sand.

Today's commander relies on staffs of varying sizes to receive, process, analyze, and interpret information. Automation will probably do little to eliminate the need for staffs; however, staffs could become increasingly more efficient with automation. On the other hand, a staff operating an automated command and control systems can become bogged down with too much information. At this point the staff is operating under conditions of information overload. Information overload occurs when the staff fails to identify the critical pieces of information from the wealth of data generated by automated systems.

The Army, through unprecedented command and control initiatives, is addressing these potential problems. In the near future, commanders will gain knowledge of the battlefield from automated displays, data communications, and interactive databases. The advanced AH-64 APACHE has the potential to receive data on moving targets from hundreds of kilometers away through airborne RADAR systems. Technology currently exists to provide an attack helicopter battalion commander, operating from a UH-60, information from a multitude of sources. When developed, this airborne command post will instantaneously receive updates from the Joint Surveillance and Attack Radar System (JSTARS), an airborne radar that collects and archives moving targets; GUARDRAIL Common Sensor (GCS), an electronics and communications intelligence (ELINT, COMINT) gathering system; and from national sources. Commanders will possess a graphical depiction of the friendly forces' advancing across the battlefield in M1 ABRAMS, M2 BRADLEYS, and tactical aircraft. They will see an automated representation of the engagement sequences and will gain an appreciation for battlefield damage in near-real time. This capability will be duplicated on the ground in battle command vehicles (BCV).

Developing enemy situations will be relayed directly to the tactical commander from airborne and exoatmospheric sensors to an intelligence cell without the time-consuming phases of analysis, classification, and dissemination. Higher commanders' orders will be transmitted at near the speed of light to command screens in graphical form. Microprocessors will assist in automatically filtering out unneeded and unnecessary information. Weather data, maintenance status reports, and even video from scout and attack aircraft will be immediately sent to computers in the TOC.

Enemy movement, command and control communications and RADAR locations will be detected and transmitted directly to users on the battlefield. Adjacent commanders will send and receive information from shared databases that will automatically update themselves and alert users of changes. The same capability will accompany the modern commander at any location on the battlefield. To make timely and tactically informed decisions, the commander, whether in a ground vehicle, airborne command post or on the forward edge of the battlefield, must remain aware of the situation.

Acquisition Realities

Factors, such as security, cost and systems management, can inhibit the Army's ability to fully exploit automation and communications technology as it develops. Acquisition managers must make business decisions weighing the current investment in the Army Tactical Command and Control System (ATCCS) against identifying a novel approach to developing a communications and automation architecture capable of capitalizing on rapidly-advancing technology. The ATCCS architecture is discussed in the next section. An economically sound business decision may limit opportunities for keeping up with advancing technology. The benefits of changing course must outweigh the associated costs. Conversely, technology alone cannot drive the development of systems. Concepts focused on Army needs drive Army requirements.[13]

The Planning, Programming and Budgeting and Execution System (PPBES) has inadvertently placed a multi-year developmental handicap on the procurement of any new, major system. During the PPBES process, the Army insures that the proposed system meets all criteria for purchase, while during the same period significant technological advancements are being made. A procurement process that constantly lags behind technological advances is unacceptable for the development of modern automation and communications systems. There must be a satisfactory medium between settling for previous years' technology and constantly pursuing the optimum design and never fielding anything.

The Army is currently assessing its systems' acquisition model and trying to shorten the acquisition cycle. Automation technology can become obsolete in approximately five years or less. This thesis defined a method for determining how the Army can benefit tactically from enhanced management of emerging communications and automation technologies in airborne and ground tactical command posts.

Significant progress is being made in weapon systems' effectiveness, accuracy, and their ability to see and fight at night and in adverse weather. This thesis focused on three weapon system members of the combined arms team: the M1A2 ABRAMS, the LONGBOW APACHE (LBA), and the advanced field artillery command and control systems. It assessed how they are integrated on the battlefield and brought together to support a single commander operating in a ground or airborne command and control vehicle. Each of these systems has enhanced command and control capabilities. Organizational focus is on the battalion task force operating as the main effort supported with the priority of fires and attack helicopters.

The Army Tactical Command and Control System (ATCCS)

During the Cold War, the Army developed a comprehensive command, control, communications and computer architecture called ATCCS. A discussion of this architecture is important because a replacement architecture has not been completely developed; when developed, it will rely on the ATCCS foundation to incorporate the already fielded ATCCS components. The ATCCS foundation was based on a Cold War Army with forward-deployed forces fighting in a developed theater. Operation DESERT STORM revealed ATCCS inadequacies in a fast-paced offensive operations that covered over one hundred kilometers in a single day. After-action reports showed how the common-user networks could not keep pace with the maneuver forces, and single-channel voice nets were overloaded.

The ATCCS architecture depicted five battlefield functional areas (BFAs): Fire Support, Intelligence and Electronic Warfare (IEW), Combat Service Support, Air Defense, and Maneuver (Figure 1). The BFAs are extracts from the Battlefield Operating Systems (BOS); the elements of war commanders must manage effectively for success on the battlefield.

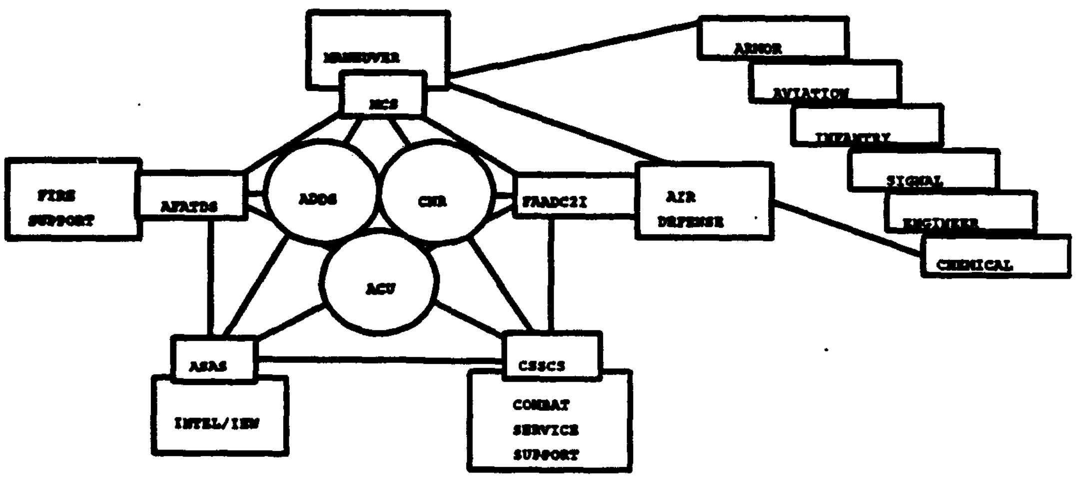

Figure 1. Cold War ATCCS Architecture

Each BFA is aligned with an Army center or school. The school is the proponent agency and develops automation and information management systems to support C2 needs for that functional area. The BFAs are supported by a common communications structure represented by the circles in the center of the star. Combat Net Radio (CNR) consists of a frequency-hopping Single Channel Ground and Airborne Radio System (SINCGARS), an Improved High Frequency Radio (IHFR), and Tactical Satellite (TACSAT) systems. The Area Common-user (ACU) system is supported by Mobile Subscriber Equipment (MSE) at the tactical level. The Army Data Distribution System (ADDS) functions are performed by joint-service and Army data communications systems. A discussion of each BFA is important.

The Fire Support BFA, managed by the Field Artillery Center at Fort Sill, uses the Advanced Field Artillery Tactical Data System (AFATDS) to transmit, receive and process calls for fire and deep strike missions. An All-Source Analysis System (ASAS) performs collection, database management and dissemination of intelligence products for the IEW BFA. ASAS automates command and control of IEW operations and intelligence fusion processing. The Forward Area Air Defense Command and Control (FAADC2) system provides timely target data to FAAD weapons to assist in management of the air battle.[14] Air battle includes all the battlefield functions performed at the air defense TOC, to include protecting friendly aircraft and engaging the appropriate enemy aircraft. The Combat Service Support Control System (CSSCS) provides automated logistics management for the tactical forces. The CSSCS becomes increasingly important in the Force Projection Army era because major logistics functions may be managed from the continental United States.

The Maneuver BFA is segmented into subordinate Maneuver Functional Areas (MFA): Armor, Aviation, Infantry, Signal, Engineer, and Chemical. Each MFA is supported by a common base of hardware and software. The hardware designated for the subordinate elements in the Maneuver BOS at the tactical level is the Lightweight Computer Unit (LCU), and the software is the Maneuver Control System (MCS). The LCU is comparable to desk top and portable personal computers (PCs) that support commanders and staffs at the tactical level. This move toward commonality was intended to generate commonality, decrease cost, and insure interoperability. The program is known as Common Hardware/Software (CHS). The most important aspect of MCS is that it is the nucleus of command and control automation for all the MFA subordinate systems. Within the maneuver BFA, each member designed a sub-architecture to support its unique needs. Army engineers developed MCS-Engineer to automate terrain analysis and other engineering functions; the chemical school designed the Advanced Nuclear, Biological and Chemical Information System (ANBCIS). Signal operating instructions (SOI) were automated by a Battlefield Electronic Communications Electronics Operating Instruction (CEOI) System (BECS).

The Post-Cold War Era

Today, the world no longer has dual super powers, polarized alliances or a clearly defined threat. Historic adjustments are being made to the Army's doctrine, training, organization and employment; its command and control structure must also change appropriately. The Commander of the Army Training and Doctrine Command (TRADOC) directed on February 7, 1992, that the U.S. Army Combined Arms Command (CAC) should accomplish the following task:

> [To] review in detail and validate architecture requirements, programs, and C2 systems, with emphasis on C2 for mobile operations, in light of the need for a versatile, downsized, Post Cold War Army.[15]

This directive represented a change in focus that initiated an entirely new direction for future C2 systems design, development, and requirements. A smaller, more capable Army would encounter missions, environments, and C2 structures that did not fit current doctrine or typical command relationships and that covered the entire operational continuum. These directional changes increased the importance of interoperability among weapon systems, mobility, survivability, and the existence of robust command, control, and communications systems. Focus has shifted to contingency operations in undeveloped theaters of operations without the luxuries of existing communications, facilities, or even a friendly populace.

ABRAMS Main Battle Tank, M1A2

The mission of the ABRAMS tank is to close with and destroy enemy forces using mobility, fire power and shock effect. The 120mm main gun on the M1A1 combined with the powerful 1500 HP turbine engine and special armor make the

ABRAMS particularly suitable for attacking or defending against large concentrations of heavy armor forces. Additional features of the M1A1 are increased armor protection, suspension improvements and an NBC protection system that provides additional survivability in a contaminated environment. The M1A2 development program builds on the M1A1 to provide an ABRAMS tank with the necessary improvements in lethality and survivability required to defeat the threat of the mid-nineties. Improvements being developed for the M1A2 include a Commander's Independent Thermal Viewer, an Independent Commander's Weapon Station, Position Navigation equipment, and a distributed data and power architecture.[16] This thesis concentrated on the distributed data, command and control architecture, and the M1A2's ability to integrate with the combined arms team.

Longbow Apache, AH-64D (LBA)

The AH-64 APACHE is the Army's primary attack helicopter. It is a quick-reacting, airborne anti-tank weapon system. Terrain limitations and the unknown placement of numerically superior enemy armor dictate the need for a system that can deploy quickly to the heaviest enemy penetration and destroy, disrupt, or delay the attack long enough for friendly ground maneuver units to reach the scene. The APACHE is designed to fight and survive during day, night, and adverse weather throughout the world. It is equipped with a Target Acquisition Designation Sight and Pilot Night Vision Sensor (TADS/PNVS) which permits its two-man crew to navigate and attack in darkness and adverse weather conditions. The principal mission of the APACHE is the destruction of enemy armor with HELLFIRE missiles. It is also capable of employing a 30mm chain gun and HYDRA 70 (2.75 inch) rockets that are lethal against a wide variety of targets. The APACHE has a full range of aircraft survivability equipment and has the ability to withstand hits from rounds up to 23mm in critical areas.[17]

The LONGBOW program adds a millimeter wave radar to the rotor mast and enhances most of the helicopter's subsystems. In addition to a progressive command and control system, the LBA will use advanced millimeter wave RADAR, three integrated data buses and onboard computers to search for, track and classify wheeled and tracked vehicles. A Battle Captain sectors the engagement area and data bursts to flight members a graphic display of their areas of responsibility. This scenario represents command and control at the lowest level. During flight, the Battle Captain monitors the location, fuel and weapons status of team members with an automated query/response system built into the aircraft's communications suite. New technology called Phototelysis will add another dimension to the APACHE's capabilities. Phototelysis allows the APACHE crew to send images from the night vision, television, and command and control systems over a voice radio to TOCs and intelligence centers throughout the battlefield.

Advanced Field Artillery Tactical Data System (AFATDS)

AFATDS is the multi-service (Army/Marine Corps) automated fire-support command, control and coordination system of the Army Tactical Command and Control System (ATCCS) which satisfies the fire support requirements of Army Doctrine. AFATDS will provide integrated, automated support for the planning, coordination and control of all fire support assets (mortars, close air support, naval gunfire, attack helicopter, and offensive electronic warfare), execution of counterfire, interdiction, and suppression of enemy targets for close and deep operations.[18] AFATDS is the key command and control gateway to a variety of fire support munitions from traditional artillery support and mine fields to advanced long-range missile systems that have the capability to destroy area targets from many miles away.

The Battle Command Vehicle

The commander must position himself at the critical place and time to use his knowledge, experience and training and presence to influence the battle. This need exists at all echelons of command--from company to corps. On a highly lethal battlefield, commanders need a survivable, mobile information processing center. The Operational Concept for the Command and Control Vehicle (C2V) describes the need in tactical terms:

> An efficient command and control platform is needed to systematize and expedite the process of providing a fully integrated, interoperable, and seamless C2 architecture for command posts of maneuver battalions and brigades, cavalry squadrons and regiments; division TACs [forward tactical operations centers]; and corps TACs.[19]

The C2V program will develop a ground variant and an airborne variant that will, through advanced communications and automation systems, provide the means to "receive information and data during battle; prepare and transmit the critical information needed by the commander; and control forces and functions of the battle based on the commander's intent and his direction."[20] Communications and computer equipment will be supported by the Common Hardware/Software (CHS) concept. Changes in the Army's C2 concept and terminology will cause the system to become known as the Army Battle Command System (ABCS).

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20. *Command and Control Vehicle Final Draft Operations Concept Staffing*, 2.

CHAPTER 2

LITERATURE REVIEW

The Army initiated a program to take advantage of emerging technology with its changing roles and missions in mind. Battle laboratories represent the major focal points for improvements in doctrine, training, leadership, organization, materiel, and soldiers. The Battle Laboratories are Battlespace (Dismounted and Mounted Warfighting Battlespace), Depth and Simultaneous Attack (DSA), Battle Command (BCBL), Combat Service Support (CSS), and Early Entry Lethality and Survivability (EELS). Battlespace requires commanders to understand all of the geometric and time dimensions of the battlefield in the synchronization of forces. The DSA Battle Lab requires the simultaneous attack of an enemy throughout the depth of enemy territory to disrupt critical centers of gravity. The EELS Battle Lab is focused on initial operations of deploying forces, quickly integrating them, creating lodgements, and conducting decisive operations. The BCBL addresses the human element in the art of command and the technology that enables commanders to acquire and maintain positive command and control of forces, and to effectively manage battlefield information.[1]

Coordination with each of these organizations was necessary to fully gain an appreciation for the state of technology and Army trends. Program managers had information critical to research on the acquisition of new systems and the degree to which they may be fielded. Program managers are responsible for the critical tradeoffs as the Army makes cost-benefit decisions for major systems. Access to acquisition documents from mission need statements and operational requirements documents to contractor specifications and cost-benefit studies was essential to assess system capabilities. These documents allowed the researcher to compare the statement of original need with the technology available and any fiscal considerations that influence systems design.

A careful understanding of the key weapon systems was achieved through a review of the technical reports and system descriptions. This thesis focused primarily on the command and control properties of the weapon systems and not their destructive capabilities. In most cases the command and control and information requirements for major systems are analyzed in the Cost and Operational Effectiveness Analysis (COEA). A COEA analyzes current methods or a base case with respect to efficiency and effectiveness. The base case is then usually compared with several proposed improvement systems. Comparisons are based on the tactical and operational contributions with the associated costs. The ATCCS, AFATDS, LONGBOW, and the M1A2 ABRAMS have undergone separate COEAs. These analyses offer unique insights into the informational capabilities and requirements for each system; however, no work has been done that integrates all four systems or the sub-systems of the ATCCS architecture.

In 1988, the Assistant Secretary of the Army for Research, Development and Acquisition employed the Board on Army Science and Technology to conduct a study of advancing technologies to determine how they might influence ground warfare in the next century. Under the auspices of the National Research Council (NRC), a Committee on Strategic Technologies for the Army (STAR) was organized. In 1992 the NRC published STAR 21, which provided expert opinions on the directions of information technologies. It predicted the possibilities and technologies which will dominate the military industry for the next 30 years. While this thesis focused on a much shorter term, STAR 21 guided the researcher in constructing a vision of the transformation stages the industry will undergo as a result of technological changes.

An initial review of work in the area of battlefield automation revealed a number of varying theses. In 1992, Major Robert Townsend asserted that the Army was hesitant to incorporate battlefield automation into command and control doctrine. Major Townsend indicated that the reluctance was a result of the fear of having too much control, and that commander's could not or would not use automated tools because of a lack of confidence in computers in general.[2]

Captain Randal Dragon investigated the need for interactive voice and enhanced visual devices to give the commander a vision of the battlefield. He analyzed the commander's information needs, discussed capabilities and limitations of MCS, and made recommendations for future efforts in advanced technology. Captain Dragon felt that the keyboard should be replaced with voice interactive systems and helmet-mounted virtual reality systems.[3] His study of C2 models and informational requirements was used in this thesis.

Fred Ricci and Daniel Schutzer published a detailed assessment of military communications networks viewed from an engineering perspective. Their book, U.S. Military Communications, presents a technical discussion on the capabilities and characteristics of current military networks such as MSE and SINCGARS. The book provides the basis for understanding how networks process and deliver information to the user. Also included is an explanation of the purposes and functions of protocols, error correction techniques, messaging, and frequency optimization. The mathematical principles discussed in this work were critical in the modeling phase in determining the capabilities and limitations of ATCCS and of proposed replacement architectures.

As discussed earlier, the written directives, plans and concepts that originated in the battlelab were the foremost indicators in the marriage between the Army and technology. The Force Projection Army Command and Control

Action Plan provided invaluable information on Army directions and initiatives. The draft and approved command and control concepts, such as the Command and Control Vehicle Operational Concept and the Battle Command Concept Paper provided current concepts in light of Army trends and initiatives.

During the analysis phase, a number of references aided the researcher in developing the principles of information management theory, queuing theory, and network design. Andrew Tannenbaum's Computer Networks provided a foundation for analyzing interactive computer networks using the Open Systems Interconnection (OSI) model. The OSI model was based on a proposal developed by the International Standards Organization in 1983 to standardize protocols for communications between networks. Leonard Kleinrock produced Queuing Systems Volume II: Computer Applications that provided the mathematical basis for delay analysis of automated networks. A summary of the works of pioneers in the field of information theory was compiled by Ira G. Wilson and Marthann Wilson in Information, Computers, and System Design in 1965. This book chronicled the original work by Claude Shannon, H. Nyquist, and R. V. L. Hartley who independently developed the theory of entropy, maximum channel capacity, and the bandwidth-time relationship respectively. Additionally, concurrent studies are being cc :ted by the Combined Arms Center that analyze the command and control requirements for the Army. The Heavy Division Information Exchange Requirement Study provided essential data that was used to model the thesis network.

Modern interpretations of the introductory work done in the 1940s was found in professional magazines such as Byte, PC Computing and Military Communications. These new translations took into account newer technologies in microprocessing, encoding techniques, and communications. The Journal of the Association for Computing Machinery offered an enlightening perspective on optimization of a distributed computer network using queuing theory in an article by Keith Ross of the University of Pennsylvania. Richard Grinold and Ronald Kahn developed a two step process for analyzing information analysis in Information Analysis. Their work evaluated the performance of an information system based on results achieved in the stock market and provided, the researcher insight into modern techniques.

A pamphlet published by the Joint Staff called "Command, Control, Communications, and Computers (C4I) for the Warrior" contributed a viewpoint on the automation and communications needs for the joint warfighter. It also made an assessment of the technologies that will be critical to meeting those needs. C4I for the warrior presented a roadmap for automating command and control for all the services and discussed key considerations in managing the right technologies for military use.

Endnotes

1. Advanced Concepts and Technology (ACT) II, U.S. Materiel Command, U.S. Training and Doctrine Command, U.S. Army Research Officer, October 1993.

2. Robert N. Townsend, "Tactical Automation on the Battlefield; Who is in Control?", (Master's Thesis, School of Advanced Military Studies, U.S. Army Command and General Staff College, Fort Leavenworth , KS), 1992, 1-3.

3. Randal A. Dragon, "On Seeing the Battlefield: Defining the Tactical Commander's Needs," (Master's Thesis, U.S. Army Command and General Staff College, Fort Leavenworth, KS, (1991), 1-5.

CHAPTER 3

RESEARCH DESIGN

Can the Army Tactical Command and Control Systems (ATCCS) or developing replacement architectures effectively integrate members of the combined arms team on the tactical level? The research methodology consisted of an analysis of the Army Tactical Command and Control System (ATCCS) and its component systems (Figure 2). The processing and communications capacities were evaluated under the Cold-War architecture. The model called for the creation of a typical maneuver task force made of combined arms weapon systems. The individual weapon systems informational requirements were compared to the information-handling characteristics of the model command and control center, the Battle Command Vehicle. Individual weapon systems were assessed to determine the information generated by the platform from its unique perspective of the battlefield. The primary focus of the analysis took the viewpoint of the task force commander with operational control of the LONGBOW unit, the ABRAMS unit, and a field artillery unit in direct support. It also assessed the information generated by the higher level command, control, communications, and intelligence systems that feed the task force commander.

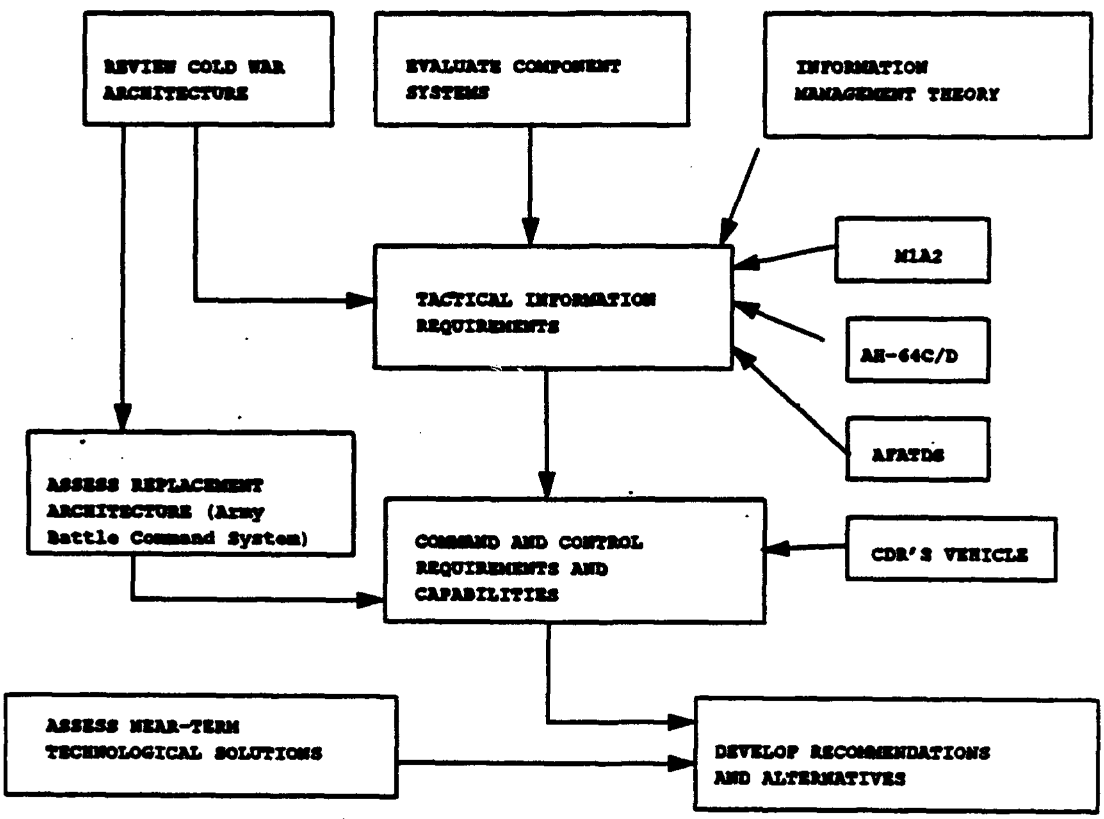

Figure 2. Research Methodology

As messages were received in the Battle Command Vehicle, independent systems working together stored and processed the messages. Each of the sources generated information that was valuable for a period of time to the task force commander. The methods available to those members to communicate information to the commander were combat net radio and MSE data transmission services. The task force was operating in a mission execution cycle characterized with multiple intelligence and command and control systems operating simultaneously from the national intelligence gathering, command, control and dissemination systems to the tactical information systems. A dynamic tactical situation caused the submission of numerous spot reports, intelligence updates, and peak loading of the communications systems. This scenario led to the presumption that an enormous amount of information is available on the battlefield, and that not all available information will be capable of being transmitted to the task force commander.

The explosive rate of development of communications and automation equipment was evaluated to estimate the effects on the command and control architecture. This evaluation tracked the development of the microprocessor and made predictions of near-term developments that could influence the replacement architecture. Next, a forecast of the capabilities and components of the replacement architecture was conducted. The enhanced capabilities of the proposed replacement architecture regulated the forecast of the Battle Command Vehicle information-handling characteristics. Principles of information theory and queuing theory formed the basis for evaluation of the levels of information being generated and the capacities of communications sub-systems. The analysis assessed the peak-loading characteristics of the primary communications systems. The Battle Command Vehicle modeled was composed of four independent and interactive work stations, a SINCGARS link to each of the subordinate commanders (ABRAMS, APACHE, and AFATDS). Each node fed the commander at predetermined rates based of the maximum channel capacities. In the model, the Battle Command Vehicle's command and control requirements and capabilities were assessed based on the variable processing times for messages of different sizes that contained battlefield information available to the platform.

Queuing theory provided the basis for calculating waiting times for messages to be processed. Data from the Network Assessment Model (NAM) were used to generate pseudo-random message sizes arriving at random times. The waiting periods calculated represented time-sensitive, perishable information at risk of being reduced in its value to the task force commander while waiting in queue. For example, intelligence data that remains in the queue past a given period, becomes worthless information to the task force commander. The Army Battle Command System (ABCS) architecture provided the foundation for message-handling characteristics. Specifically, the interactive databases and user-defined automatic update capabilities were projected into the model. Predictions of near-term technological developments were assessed as potential solutions to identified deficiencies. Based on the study findings and a review of enhancements in the automation and communications fields, concrete recommendations were then made on how the Army should proceed in developing tactical level command and control systems.

CHAPTER 4

ANALYSIS

The analysis began with an assessment of the speed at which technology is advancing and its influences on developing automation for the battlefield. Then a projection of the Army's objective architecture, the Army Battle Command System (ABCS) was presented to show its complexity and demands on technology. Then, a mathematical analysis of a typical tactical network was conducted using queuing and information theory.

The State of Technology

Automation technology is advancing so rapidly that few outside the field can understand the implications of advanced developments. Force developers for the Army's command and control systems must operate within the realm of understanding and managing automation and communications technology. Command and control systems depend heavily upon these technologies. Most of the critical components of modern automation systems are similar in design, function or both. Key aspects of a computer's capability are its central processing unit (CPU), available memory, expansibility, user interfaces, and flexibility.

Most CPUs are differentiated by their speed. The CPU is the brain of the computer and has undergone the most change in recent years. The Intel Corporation's 80386DX microprocessor was introduced in October 1985. It had 275,000 transistors.[1] The 386DX had a 32-bit bus and could run at 16 or 33 Megahertz (MHz). A data bus is a parallel array of circuits that allows the CPU to communicate with other components in the system. The DX designation means the system has a 32-bit data bus and can process and transfer 32 bits at once as compared to the SX which has a 16-bit data bus. A DX model also has a math co-processor which executes complex mathematical functions as the CPU performs other functions.

Microprocessors

The 80486 processor was introduced in April 1989. It has 1,200,000 transistors and a bus width of 32 bits, and is 50 times more powerful than the 80386. The 80486 also introduced memory caching, which further increased its speed. The 80486 also used Reduced Instruction Set Computing (RISC) technology that shortened the instruction set so the computer operated faster. It ran at 25, 33, or 50 MHz. In March 1992, Intel Corporation announced the 80486DX2 that ran at 66 MHz.[2] Figure 3 follows the chronology of Intel Corporation's microprocessor development.

Processor	Introduced	External Speed	Internal Speed	Clock Speed (MHz)
8086	1978	16 Bits	16 Bits	5, 8, 10
8088	1979	8 Bits	16 Bits	5, 8
80286	1982	16 Bits	16 Bits	8, 10, 12
80386SX	1988	16 Bits	32 Bits	16, 20, 33
80386DX	1985	32 bits	32 Bits	16, 20, 25, 30
80486SX	1991	32 Bits	32 Bits	16, 20, 25, 33
80486DX	1989	32 Bits	32 Bits	25, 33, 50
80486DX2	1992	32 Bits	32 Bits	50, 66

Figure 3. Intel Corportation's Microprocessor Development

The development dates of the SX and DX models appear reversed. The advanced models (DX) were developed first and a less capable version (SX) was marketed later to make them more affordable. The table illustrates the continuous changes occurring in the computer field.

The Pentium, or 586 microprocessor, is now available to businesses and personal computer (PC) users. The Pentium has 3,000,000 transistors and uses a "superscalar" technology that allows the computer to process more than one instruction per clock cycle.[3] The Pentium advertises a threefold increase in performance, but some independent testers report "identical software [operates] about 80 percent faster than a similarly clocked 486."[4] Still an 80 percent increase in performance is a significant enhancement since the development of the 486DX2 just a year ago.

Memory, Storage, and Speed

Memory and storage capacity of the computer are equally important. Information can be stored in a number of ways, but the key choice to make is how much storage is necessary. Today's computers will have numerous types of memory. Most computers have conventional, random access memory (RAM) extended, expanded, virtual, and high memory. Just a few years ago hard disks or drives could store about 20-40 megabytes (MB) of information. In 1992 the typical hard drive was 130 MB. Currently, hard drives can easily store more than 420 MB of applications software.

This assessment fails to address the exponential growth in storage capacity experienced when adding access to Compact Disk (CD) technology. The capacity of a read-only CD can range in gigabytes. Compact Disk-Read Only Memory (CD-ROM) is an emerging technology that every systems designer must consider. It is especially important for designers of military systems since the Defense Mapping Agency has created a terrain data base of the worlds surface on CD-ROM. This effort is making digitized maps available to users of automated command and control systems. Inadequate maps has been an impediment to a significant number of military operations.

Speed will become a major factor in the design of tactical military systems. The tactical commander will not have an abundance of time on the modern battlefield. If battlefield automation cannot provide information in a timely fashion, he will simply not use it at all. Computer speeds range from 16 to 75 MHz, but the available memory will affect how an application responds to the user.

Automated military systems have high needs for memory and storage capacity. A typical tactical system must store and process multiple maps and terrain data, archives of orders and plans, and multiple detailed courses of action. Applications must be terminated and started rapidly to respond to instantaneous changes on the battlefield.

Operating Systems

Available operating systems also vary significantly. An operating system is a computer program that coordinates the many processes of a computer's operation. It schedules the succession of jobs to be performed and allocates different tasks to different computer resources. The operating system instructs the CPU to load store and execute certain programs.[5] When a computer runs a number of programs simultaneously, the operating system allocates time and resources. A robust operating system is necessary to perform time-sharing and networking in the tactical environment.

Environments

Operating environments usually determine the level of "user friendliness" of a system. In 1984, Apple Computer Incorporated introduced the Apple Macintosh computer. At the time, it was the only graphical user interface on the market. It used intuitive "icons" or pictures to represent functions and commands. Microsoft Corporation developed the Windows environment that duplicated the look and "feel" of Macintosh. Today it would be hard to imagine a complex application being used by the novice or intermediate computer user without an environment similar to Windows. The international acceptance and widespread use of Windows offer a unique opportunity to capitalize on a "standard" common to the home, office, and marketplace. Windows is now the most popular environment, but many alternatives exist in the marketplace.

Processors on the digital battlefield will split their energies between running applications and an increasing demand for user interfaces. Simpler user interfaces require more processor time, and simple interfaces are necessary in the introductory phases of automating the force. "In the 1950s, . . .less than 5 percent of all CPU cycles were devoted to the user interface; today it is probably close to 50 percent and continuing to increase."[6]

Automation will never fully replace human interaction. This thesis assessed the ability of current and near-term automation and computer technology to receive, process, and display the enormous amounts of information available on the modern battlefield.

These are but a few of the components of battlefield automation. They must be understood by the communications systems designer who expects to capitalize on the state-of-the-art technology. The designer must also realize that "evolutionary developments in random access memory, storage, and spe ' . . . will increase by a multiple of 1000 by the turn of the century.[7] The Post-Cold War Command and Control Study completed in August 1992 identified four key technology enhancements for automation. They are "improvements in source data entry, visual display and projection of graphics, three-dimensional terrain visualization, and map overlay graphics distribution."[8] The study designed a replacement architecture for ATCCS that focused on a seamless flow of information, integrated automation and communications, processing on the move, and a constant receipt and distribution of combat information. All the factors that enhance command and control capabilities require close scrutiny to get the appropriate mix and match throughout the tactical network.

The Replacement Architecture: The Army Battle Command System (ABCS)

> The Army Battle Command System (ABCS) is the integration of fielded and developmental battlefield automation systems and communications employed in both training and field environments, in both developed and undeveloped theaters, and in either fixed/semi-fixed installations and mobile networks.[9]

Before an accurate assessment of the tactical command and control architecture can be accomplished, an examination of the objective architecture is necessary. When the Army concluded that the Cold War command and control architecture was inadequate for the Force Projection Army era, numerous deficiencies were identified and a replacement architecture was developed. The replacement architecture is the Army Battle Command System (ABCS). This architecture remains in transition. The ABCS will replace the "stovepipe" information distribution of ATCCS with a distributed database (Figure 4).

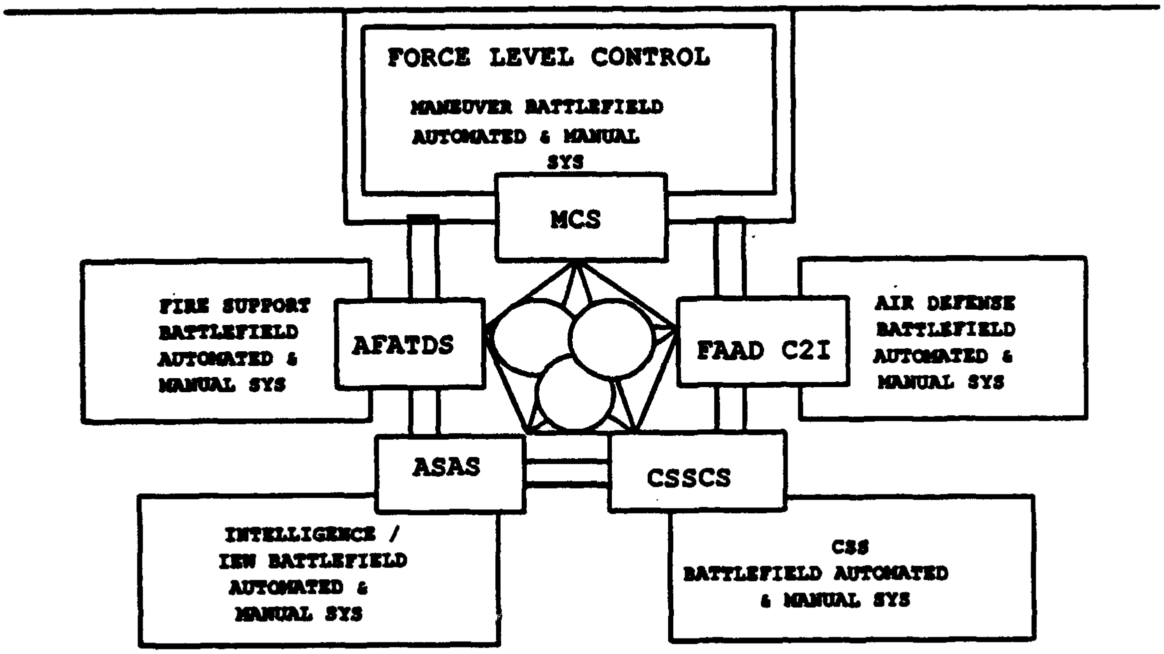

Figure 4. Revised ATCCS Architecture

It will also integrate previous higher and lower level command and control systems: Army World-Wide Mil`tary Command and Control Information System (AWIS), Standard Theater Command and Control System (STACCS), and Army Battalion and Below Command and Control System (AB2).

Users will access information with queries to a "virtual" master database that is physically made up of separate and distinct information pools invisible to the user. The revised ATCCS architecture contains a seamless environment for information management which eliminates the applications independently developed by each MFA and BFA. These applications are replaced by a common core software package which supports modular application software for each user. The applications are interchangeable and flexible. The user tailors his package based on the mission and environment. The ABCS makes applications more accommodating to commercial off-the-shelf software packages. It adds broadcast technology for command information processing direct to users. It fully integrates communications and automation technology, provides for processing on the move, and provides the constant receipt and distribution of combat information. The objective architecture is described as follows:

> In its objective form ATCCS [ABCS] will provide warfighters a tool and decision aide for managing large amounts of data, the ability to track both friendly and enemy status on a near real time basis, the ability to prepare, coordinate, and disseminate plans, orders, graphics, and reports much faster than ever before, and a shorter planning and decision cycle that allows all echelons more time to plan, prepare, and execute combat operations.[10]

These needs were validated by the Post Cold War Command and Control Study of 1993.

At the tactical level the enhancements focus on the Battle Command Vehicles (BCV). The BCV will be located at brigade, division, and corps and used as forward tactical operations centers (TACs), main command posts, and battalion TACs and Administrative and Logistics Operations Centers (ALOCs). The battalion TAC is the center of focus for this thesis. It is the critical link between the operational commander and the tactical commander who must integrate advanced weapon systems (e.g., ABRAMS, LONGBOW APACHE, and Advanced Filed Artillery Weapons), intelligence data, and command and control functions.

The commander of the automated combined arms team must have enhanced communications, processing and display systems.[11] His vehicle must operate on the move. It must provide the means for the commander to exchange information over wireless local area networks with adjacent commanders, intelligence ground stations (Common Ground Station), and automated weapon systems. Connectivity with and use of existing ATCCS subsystems is also necessary to maintain linkages with force level and theater level systems.

This assessment gauged the information generated and needed by company teams in a typical battalion task force in a battlefield environment. The LONGBOW commander may have as many as 24 subordinate aircraft in one flight. Each RADAR system can scan, classify and track 256 targets in an engagement area, but the platform generates significantly more information that may or may not be of use to the task force commander. The LONGBOW APACHE's three data buses process and generate information that is used to manage weapons, fuel, navigation, and communications systems. The internal systems also process data from imaging systems (low-light television and infrared) and command and control data for the LONGBOW team.

An ABRAMS commander relies on a single data bus to manage position/navigation (POS/NAV) data, friendly and enemy positions, imaging, weapons, command and control, and targeting systems. His automation system must collect, process, and manage the information generated by up to 56 subordinate automated tanks and submit periodic or on-call reports to the task force commander. Artillery commanders are primary receivers of information; however, the task force commander must remain aware of his supporting artillery's position and capabilities. The task force commander receives, processes, and manages all the subordinate-generated information, operations orders and intelligence data from superiors, and uses it to make tactical decisions.

Communications capabilities were key to the analysis because in some cases the communications system was the limiting factor in the amount of information capable of being generated or processed. The LONGBOW commander has a communications suite that allows him to operate in multiple nets. He must operate in multiple air-to-air and air-to-ground communications nets. The ABRAMS commander operates in primarily two operational nets, command nets to higher and lower echelons. Common to both combat systems and the Battle Command Vehicle is the SINCGARS radio. The SINCGARS was developed primarily as a digital voice radio, but its capabilities are becoming critical to data transmissions at lower echelons. It is the key communications link from the task force commander to subordinate commanders. SINCGARS can operate in the single-channel or the frequency-hopping mode handling a data stream at 16 Kbps in a frequency range of 30 to 76 MHz.[12] Error correction is only available at or below 4800 bps.

The Battle Command Vehicle has multiple and duplicate communications systems allowing the commander to operate in multiple nets simultaneously. The Battle Command Vehicle is supported by the Army Brigade and Below (AB2) sub-architecture of the Army Battle Command System (ABCS). Information entering the Battle Command Vehicle from higher echelons will have numerous sources and come from databases from throughout the battlefield, but most if not all, higher echelon information will come through the brigade operations center. The operational requirements document for the ABCS describes this sub-architecture as follows:

> The AB2 architecture is a suite of digitally interoperable, BOS specific functional applications, designed to provide near real-time situational information to tactical commanders, on-the-move, down to platform/squad level. AB2 will provide the friendly automated positional location information, to include display of adjacent units to platform level resolution; current tactical battlefield geometry for both friendly and known/suspected enemy forces automated situational reporting, calls for fire/close air support; and disseminate graphic and textual orders.[13]

This analysis model required that all information from and to the team go through the battalion task force commander's TOC. This step led to an assessment of the information-handling capabilities of the proposed Battle

Command Vehicle. In looking at the Battle Command Vehicle, the following sources of information were considered:

1. Intelligence from sensor systems direct to the higher level commander's operations center.

2. Intelligence sent through the ASAS.

3. Command and control information fed from higher headquarters.

4. Tactical information from adjacent units.

5. Information generated by the task force itself (SITREPS, LOGREPS, etc.)

6. Information generated at the BCV (Commander's decisions, requests for updates, coordination, etc.)

7. Air defense and missile warnings.

8. Terrain and weather data.

The centerpiece in the Battle Command Vehicle is the lightweight computer unit (LCU) and the transportable computer unit (TCU). Current prototypes of the LCU are 20 pound portable computers with a 80486 32-bit microprocessor, a 10 inch screen, and 32 megabytes (MB) of random access memory (RAM). The LCU is a desktop-sized computer with a 200 MB hard drive, internal LAN access, a Hewlett-Packard 380 processor, and 32 MB of RAM. Added to the LCU is an external mass storage expansion unit (MSEU). The MSEU is composed of an additional 380 MB hard drive, 650 MB magneto-optical drive, and a 600 MB CD-ROM.[14]

The analysis proceeded with a delineation of the parts of information and queuing theory critical to the model. Principles of information theory formed the basis for determining the maximum link capacities, and queuing theory was used to calculate the network processing times and message handling characteristics.

Delimitations

The following delimitations were instituted to sufficiently narrow the scope of the thesis:

1. Electronic jamming or interference of communications was not considered because there is no clearly defined threat whose capabilities can be assessed and applied to the analysis model. Accurate predictions of the environment with respect to jamming, interference, and noise were not possible. Therefore, the communication channels were modeled as noise free.

2. Data communication was considered as the primary means of communications because the Army has established a

trend toward "digitization of the battlefield" where data is becoming the predominant method of communications on the modern battlefield.

3. This thesis did not consider human error to avoid analyzing behavioral aspects of combat operations.

4. The study focused on operations only during the execution phase because it is the most likely period of maximum work load for the communications and automation systems.

5. Only tactical combat operations were modeled to avoid analyzing the logistics automation systems and processes.

Limitations

The following limitations were imposed by the nature of communications and automation technological development:

1. Predictions of technological developments were not precise. It is not possible to predict scientific development with certainty.

2. It is not certain the Army will continue it current trends toward automation on the battlefield. The

Army operates on budgetary imposed by congress and may be required to shift to alternative strategies.

Information Theory

Information theory, also c .e theory of communications, is a branch of probability theory that provides a measure of the flow of information from an information source to a destination. It also supplies a measure of the channel capacity of a communications medium such as a telephone wire and shows the optimal coding procedures for communication. Although originally concerned with telephone networks, the theory has a wider application to nearly any communication process. Information theory was developed to a great extent at the Bell Telephone Company laboratories in New Jersey under the auspices of Claude Shannon in the 1940s and 1950s.

The principal features involved in information theory are a source of information that is encoded and transmitted on a channel to a receiver, where it is decoded. There are two versions of information theory, one for continuous and the other for discrete information systems. The first theory is concerned with the wavelength, amplitude, and frequency of communications signals; the second is associated with the random processes associated with the theory of automata.[15] The discrete theory applies to a larger range of applications and was developed for both noiseless and noisy channels. (A noisy channel contains unwanted signals and requires a filter to properly receive the transmitted message. A noiseless environment is conducive to a pure analysis of capacity loading and queuing.)

Queuing Theory

Queuing theory is the branch of probability theory that studies the behavior of queues, or waiting lines. Queuing theory seeks to predict the behavior of the waiting lines so that informed decisions can be made regarding how much service capacity should be made available.

The first element of a queuing model is an input process, which describes the pattern of arrivals over time. The arrivals in this model are not regular, but rather are random. The second element is a description of the service mechanism, in this case the computer processor. The Battle Command Vehicle has multiple processors or servers and multiple paths to each server. Because the data base within the Battle Command Vehicle is a virtual database (one that has physically separated components, but this property is transparent to users inside and outside the vehicle), arriving messages appear to arrive in a single line. This phenomenon is a result of the properties of the virtual database; from the viewpoint of the users and the processors it is a single entity.

The computer processors also have random aspects. The service or processing time varies from case to case. For example, messages that contain graphics are larger in size and require more processor time than pure text messages. As the message arrival rate increases, the utilization increases and the system becomes congested. So the probability distribution of service or processing times was specified in the model as exponential.

The notation A/B/m is widely used in queuing literature, where A refers to the distribution of interarrival times, B represents the distribution of service times, and m is the number of servers.[16] The most common distributions is M, where: M = an exponential probability density (M stands for Markov).

In the M/M/1 model has one server, exponential service times, and random and independent arrivals. A probability density of this type generates Poisson distributed arrivals.

In 1964, Leonard Kleinrock showed that in an M/M/1 queuing system, a communications channel, *i*, with capacity, C_i bits/sec, and a message processor with an exponential probability density function of packet size, x bits, equaling $\mu e^{-\mu x}$, the following relationships exist: the service rate is μC_i packets/sec, the arrival rate is λ_i packets/second, and the total waiting time can be described as:

$$T_i = \frac{1}{\mu C_i - \lambda_i}$$

where T_i includes both transmission and queuing time.[17]

Channel Capacity

The analysis of the tactical network supporting the combined arms team began with the identification of the nodes involved in the process. For the pu es of evaluation, the members of the combined arms team were consolidated by type of information source. For example, the LONGBOW commander will have numerous C and D model APACHES subordinate to the LBA commander, but all information flowing to the task force commander must go through the LBA commander (Figure 5).

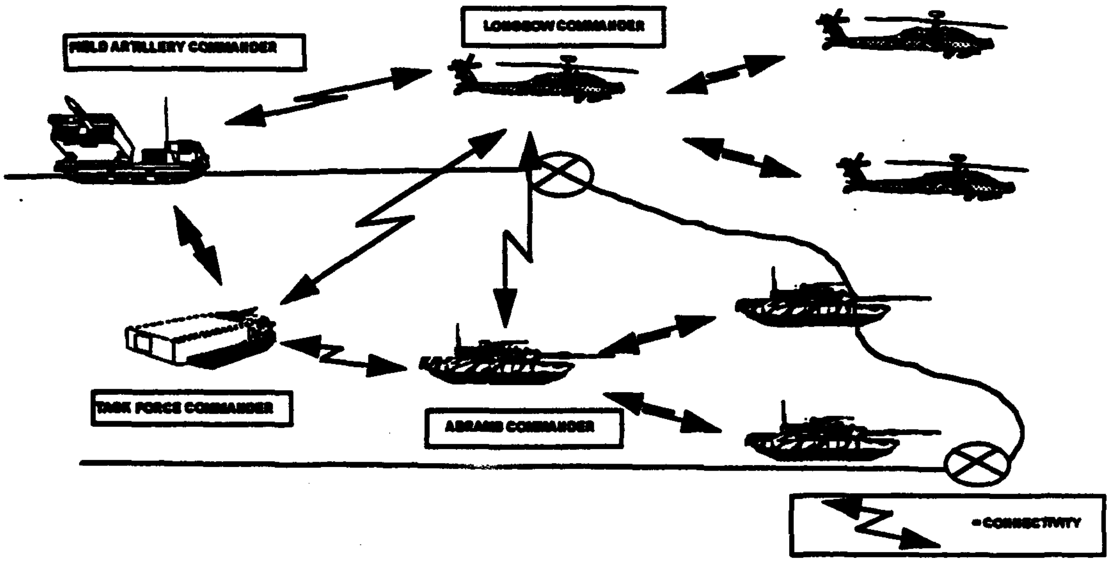

Figure 5. The Tactical Communications Network

Therefore, the LONGBOW component can be considered a single information source. Likewise, the ABRAMS commander serves as a single source for information flowing to and from the ABRAMS component. The information sources are connected to the task force commander through a single communications link, the SINCGARS radio. [A similar philosophy (creating a single information source) was applied to the higher echelon command, control and information structure, the only difference being the multiple communications means available on this link constituted a higher capacity node.]

A communications channel's maximum capacity is determined by the physical properties of the bandwidth, data rates, noise, and selected modulation and encoding techniques.[18] R.V.L. Hartley determined in the late 1920s that, in a noiseless environment, the maximum quantity of information that can be transmitted over a communication channel can be described as follows:

$$C = 2WT\log_2 L$$

where C equals the quantity of information, W equals the bandwidth of the channel, T is per unit time, and L represents the number of distinguishable signals.[19] Therefore, the maximum channel capacity for a SINCGARS link is 2(16 Kbps)(1 sec)$\log_2$(2) bit/sec or 32 Kbps (Figure 5). The actual data rates were applied to Hartley's theorem because the data rate is more representative of the available information capacity than bandwidth. Modern coding and compression techniques have allowed current communications systems to surpass physical limitations of bandwidth.

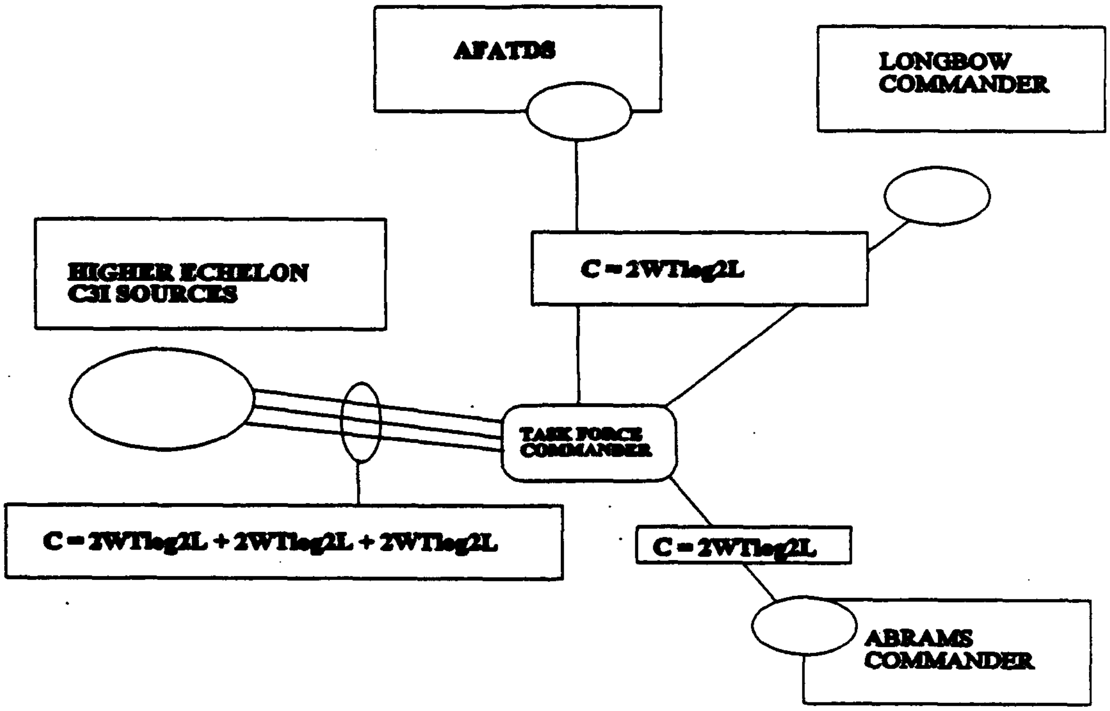

Figure 6. Information Loading and Channel Capacity

Maximum data rates use all available bandwidth for messages and does not allow for error correction. SINCGARS can provide error correction only up to 4800 bps, so this rate may be more realistic to model. The maximum information capacity at a 4800 bps data rate is 9600 bps (2 X 4800 X $\log_2(2)$) using Hartley's bandwidth-time relationship. Using a standard 8-bit character word, this translates to 1200 ($\frac{9600}{8}$) characters per second. The Improved High Frequency Radio (IHFR) operates on a 100 hz bandwidth and supports data rates up to 2400 bps when used with special data modems.[20] The IHFR link will support an information rate of 4800 bps at maximum loading. For the purpose of evaluation, the task force commander has 3 SINCGARS links, 1 mobile subscriber radio terminal (MSRT) operating at 4800 bps, and 1 IHFR link operating simultaneously and intermittently during a critical operation. The mean information rate at the Battle Command Vehicle was determined by adding the three 4800 bps-SINCGARS links to the MSRT and IHFR links operating at 4800 bps and 2400 bps respectively (yielding information rates of 9600 and 4800 bps). The maximum information rate became [(9600 X 3) + 4800 + 9600] = 43200 bps or 5400 characters per second. This number represents the maximum channel capacity. From this number, the mean arrival rate was calculated by dividing the number of inputs into the system which revealed a mean arrival rate of 8640 bits/second. This situation creates some inherent waste of bandwidth since when a channel is idle, it cannot be used by another user. Then T in an environment of multiple separate inputs becomes:

$$T = \frac{1}{\mu(C/N) - (\lambda/N)} = \frac{N}{\mu C - \lambda}$$

The Heavy Division Information Exchange Requirement Study (IERS) study modeled a heavy division in a Southwest Asia scenario during a breaching operation. The interim report for the IERS revealed that a maneuver brigade could process more than 10,000 data messages in a 24-hour period for operations traffic alone. An armor battalion S-3 section transmitted and received 11,578,808 characters in a single 24-hour period.[21] The study also showed that other BFAs would place a lesser, yet considerable, demand on communications and processing capabilities. Previously, this thesis showed that message length was a determining factor in calculating processing time. This thesis used sample message data from the IERS to evaluate typical message sizes in a high-intensity operation. The message lengths ranged from 900 to 2500 characters with a mean value of 1505 characters per message or 12045 bits per message.

The mean message length was then compared to the arrival rate to estimate the mean number of messages arriving per second calculated earlier. The mean arrival rate was divided by the mean message length ($\frac{8640}{12045}$) to obtain the number of messages arriving in a 1 second interval. On the average .7173 messages will arrive every second which equates to approximately 43 messages per minute. Using the calculated values for the mean arrival rate, channel capacity and an estimated mean processing time, the delay was calculated as follows:

$$T=\frac{5}{\mu C-\lambda}=\frac{5}{(2*43.2)-.7173}=0.058\ msec$$

The central element of the system is a server that provides some service to items. Items from some population of items arrive at the system to served. If the system is idle, it serves the item immediately; otherwise, an arrival item joins a waiting line. When the server has completed serving an item, the item departs, and if there are items waiting in the queue, one is immediately dispatched to the server. The server handles incoming messages with an average service time, μ.

Utilization, indicated by the Greek letter rho, ρ, is the fraction of time that the server is busy, measured over some interval of time. As the arrival rate in a system increases, the utilization increases, and the system becomes congested. The waiting line becomes longer, increasing waiting time. At $\rho = 1$, the server is saturated, working 100% of the time. So, the theoretical maximum input rate the system can handle is as follows:

$$\lambda_{max} = \frac{1}{\mu}$$

Waiting lines become very large near system saturation, growing without bound when $\rho = 1$. No practical system can operate at 100% due to practical considerations such as buffer size, processor time required for operating systems and environments, and response time requirements.[22] A typical system breaks down at 70-90% loading. Analysis continued under the following assumptions:

1. An infinite population exists (there is more information available that can be transmitted to the task force commander).

2. The queue can grow without bound. The buffer can store an infinite number of messages.

3. When the server becomes free, and if there is more than one message in the queue, a decision must be made as to which message to dispatch to the server. This model assumed the first-in, first-out approach.

In an M/M/1 environment with exponential service times and Poisson arrivals, the following relationship exists:

The mean utilization factor = ϱ =

$$\varrho = \lambda \mu$$

where s = the mean processing time. Using the calculated values for the proposed network, these parameters were calculated as follows:

$$Utilization = .7173 \; x \; 2 = 1.4346$$

This factor shows that with a 2000-bit per second processor, the system will become overloaded during peak periods. To obtain a 60% utilization, the most time that can be spent on the average with any one message is .836 seconds (solving for μ, where $\rho = .60$). It is important to note that the utilization factor must include the processing required to run the operating system and environment.

This analysis has shown that with currently available technology, a typical tactical network became overloaded during critical events. In the model developed for this study, the battalion task force could not process the messages generated by the subordinate members and higher echelon C3I sources. An overloaded command and control system can adversely affect military operations by denying a commander critical information. This model represents the minimum design requirements for a tactical system. High speed processors will be key in the design of modern military systems to deal with the inherent delay created by automated information systems. The optimum tactical command and control system must have the available resources to deal with the ever increasing demands for processor time and memory.

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CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Communications and automation technology are critical to command and control now and in the future. This study built a simplified model of a small portion of the command and control infrastructure. It is a microcosm of the tactical, operational and joint information architectures of the near future. This significantly limited model has shown that the digital battlefield will have new challenges for the commander and the communicator. Digital technology brings enhanced capabilities, but it does not represent a paragon of information. Information management will continue to be a remarkable business for the technologically capable. This study has shown that significant changes will occur in the communications and automation industry in a very short time and that to exploit effectively those changes, system designers and engineers must pay close attention to the needs of the user and provide the technology that meets those needs at a reasonable cost. This aspect of technology management is especially important to the military designer because a disparity exists between military needs and current capabilities.

In recent tests, immediate results from digitizing the battlefield are apparent. Accuracy rates for messages are running at 98 percent as compared to 22 percent for voice.[1] Digital technology brings with it other obvious enhancements over voice. Speed of transmission will immediately reduce on-the-air times and make enemy intercept and direction finding efforts more difficult. Commanders will make an assessment of the battlefield with a glance at high-speed situational displays, and lengthy conversations on the radio may become obsolete. Firepower will be improved through increased accuracy and speed. Commanders will bring overwhelming combat power to bear at the critical time and place on the digital battlefield with unprecedented synchronization. Initial testing showed a 15 percent increase in direct fire rounds and a 5 percent increase in indirect fire rounds in a Southwest Asia scenario, and errors were reduced by 60 percent.[2]

Completely interactive systems present certain inherent problems. The architectural nature of ABCS will make it intolerant of errors. Incomplete or inaccurate information could spoil the database or cause multiple reporting. Keeping up with a rapidly changing maneuver picture will become more challenging. These factors increase the criticality of fusion technologies that automatically scrutinize the inputs of multiple sensors and correlate the picture provided to commanders.

> Fusion is the process of receiving and integrating all-source, multimedia, and multi-format information to produce and make available to the warrior an accurate, complete, and timely summary of essential information required for successful prosecution of operational objectives. Fused information is more valuable to the warrior than information received directly from separate, multiple sources to the degree that it provides the warrior with the real truth.[3]

This definition identifies an intrinsic conflict between timeliness and accuracy. Should commanders wait for complete accuracy obtained through fusion and analysis or be provided raw data immediately? Time-consuming analysis and over classification of information have historically been the factors that have kept critical tactical intelligence from the hands of past commanders. Artificial intelligence is currently the only feasible technology that can manage this level of information processing.

Electronic surveillance remains an imperfect science, and an insightful adversary will attempt to exploit our growing reliance on automation for battlefield information. Security is a key component to the new architecture. Multilevel security is a two-edged sword. It must protect the system from unauthorized access while providing a benign interface to an extraordinary variety of users throughout the battlespace. Cryptological key management must mature rapidly to keep up with a diverse and growing network.

Any novice database manager knows the importance of asking the right questions when working with computer databases. Because of near universal access, commanders on the digital battlefield will be challenged with what to ask for and when. These decisions will ultimately determine how his local database is updated. Which information will be sent automatically (pushed), and which will be sent on demand (pulled) are significant decisions that must be addressed during the planning phases and periodically during the execution phases. Commanders and staffs develop a list of critical information requirements when planning an operation. A failure to ask the right questions could render a database ineffective. Commanders and staffs must have an understanding of the capabilities of joint C4I systems to maximize its potentials.

The Future of Technology

Developing a command, control, and communications system in an environment with rampant technological development is not an act; it is a process. Unless technology reaches a plateau in capability, this process will be continuous. If the last ten years is indicative of the future, technological breakthroughs will continue. "Continuous reductions in the size of both transistors and wires have allowed an increase in the number of devices that can be put on a single silicon die. This means that the same size die can now contain roughly 10 times as many transistors as before [1982]."[4] An end is not in sight for these type increases in capacity because as micro-chips get smaller, more chips can fit on a single board. Memory density has also seen significant increases in capability. Memory densities have increased by a factor of four every three years. In the last 10 years, clock cycles have been improved by a factor of 50. Cost has consistently decreased as capability increased.[5]

The Army's needs may be better served if a more temporary approach were taken. Instead of trying to purchase a system that will meet its needs for the next 10 to 20 years, the Army should consider the useful life span of automation systems and capitalize on current potentials while building in growth. Taking this philosophy one step further would require developers to plan and allocate resources for system upgrades in five to seven years.

Bandwidth expansion technology is the next step to improve performance in a computer-based network. Manipulating available bandwidth is a two dimensional problem. One dimension exists within the computer. It determines how fast instructions are passed and executed between the processor and peripheral devices, and it determines access time. A low access time is critical to graphic-intensive user interfaces. Parallel processing, reduced instruction sets, and increasing the number of instructions per clock cycle are developing methods to compress computer workloads. The second dimension exists between computers. A local area network (LAN) operates much faster than a dial-up network. The available bandwidth for a coaxial cable is greater than a wire pair or a single-channel radio. Operating radio-connected automated networks at speeds that approach that of a LAN will require higher bandwidth tactical communications systems. The laws of physics dictate that as bandwidth increases, range decreases in the radio frequency spectrum. Tactical communications centers will require a balance of range and bandwidth so that the benefit of high-speed onboard processors are not lost in queue waiting for a slow communications system. Data compression and multilevel coding are techniques that may provide higher information transfer rates in the short term. "The demand for more speed, greater bandwidth, and integration of voice, data, and image on a single medium will continue."[6]

Avoiding Information Overload

The potential for information overload continues to be a threat on the digital battlefield. Interactive databases, faster clocks, and other enhancement technologies will make [information] available to typical users 10,000 times what is available now.[7] Every bit of processing power available will be needed and used. Processors on the digital battlefield will split their energies between running applications and an increasing demand for user interfaces. Simpler user interfaces require more processor time, and simple interfaces are necessary in the introductory phases of automating the force. "In the 1950s, . . . less than 5 percent of all CPU cycles were devoted to the user interface; today it is probably close to 50 percent and continuing to increase."[8] At the same time, applications are becoming more complex. A balance must be found between CPU time for the operator and the operation. The Army recognizes this fact and acknowledges the need for near-real-time decision aids. In the near-term, simple decision aids will be necessary to manage the CPU's time effectively. Developers must then look toward the super microprocessor or advanced artificial intelligence systems to supervise the user interface-application time conflict. The super microprocessor is a conceptual microprocessor design that through multiprocessing (placing multiple processors on a single chip), super fast clocks (250 MHz or greater), or wider bandwidth (64-bit word lengths) will eliminate contention for CPU time.

The future of operating environments contains similar evolution. Speed and user friendliness will be the determining factors in a time-sensitive, interactive architecture. Multi-tasking environments will be a necessity for the military system designer. Processors will have to perform multiple tasks simultaneously and be reconfigured rapidly for unanticipated changes in the user's needs.

Artificial intelligence technology may not mature fast enough to participate in the first information war. The tactical user knows his needs best. It is imperative to get interim automated systems to field units to acquaint them with the technology and to get feedback from the future users. The Army cannot afford to wait to develop the ultimate system.

Conclusions

Digitizing the battlefield is a manifestation of an effort in the military and civilian environments to take control of an information explosion. The greatest problem maybe a basic human resistance to change. This problem is evident in congressional debate over who will control the "information superhighway." The first step toward getting a grasp on the massive changes happening in the industry is to discard the traditional ways of doing business. This step was taken in the military environment when an insightful TRADOC commander created the Battle Laboratories. Realizing that the Army acquisition system was incapable of adequately managing the technology explosion, General Fredrick Franks conceptualized a new technology management philosophy. Now, less than three years later, the Army is on the threshold of fielding its first digital brigade, Task Force 2000.

These events could not have happened at a better time. In an era of dwindling resources, and restructured roles and missions, inevitably, America's armed forces will be expected to do more with less, to win without the benefit of superior numbers. Digitization provides the technological edge to do just that. The force could not have been more ready. This generation of soldiers has been called the "Nintendo generation" because they grew up with computers, games, and simulations. That cultural phenomenon can now be capitalized on by exploiting basic computer knowledge and familiarity and eliminating computer-phobia on the battlefield. Decisions made today on when, where and how much we focus technology will determine whether we win the first information war.

> "We are in the information age. The revolution is underway"[9]
>
> Lieutenant General (Ret) Emmett Paige Jr.

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